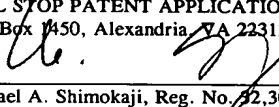


"Express Mail" label number **EL964766148US**

Date of deposit 12/10/03

I hereby certify that this correspondence is being deposited with the United States Postal Service "Express Mail Post Office to Addressee" service under 37 CFR 1.10 on the date indicated above and is addressed to: MAIL STOP PATENT APPLICATION, Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.

  
Michael A. Shimokaji, Reg. No. 32,303

**PATENT**  
**H0005725-1050**

## **BIMETALLIC PLATE-FIN TITANIUM BASED HEAT EXCHANGER**

### BACKGROUND OF THE INVENTION

5   **[001]**       The present invention generally relates to a heat exchanger of the plate-fin type for use in oil coolers, condensers, evaporators, etc., and more particularly to a heat exchanger of the plate-fin type having fins of one metal brazed to a plate made of a different metal.

10   **[002]**       The plate-fin type heat exchanger has a large area of heat transfer per unit area and a high coefficient of heat transfer, and therefore, has an advantage in that it is compact and relatively easy to manufacture in comparison with other types. Also, the plate-fin type heat exchanger has a wide range of design variations available, such as the fin pitch, the fin height and the fin shape. These variations may be chosen to provide a heat  
15   exchanger suitable for the nature and the purpose of the fluid flowing through each passage.

20   **[003]**       Referring to Figure 1, a conventional plate-fin heat exchanger 100 may be made by brazing a first set of fins 110 to a one side of a metal plate member 120. A second set of fins 130 may be brazed to the other side of metal plate member 120. Fins 110 and 130 may be configured to provide a counter-current flow (not shown) or a cross-current flow between the first set of fins 110 and the second set of fins 130. Flat plates 140, 150 may be brazed to fins 130 and 110, respectively, to provide cross or counter-current-flowing fluid passages A and B.

25   **[004]**       Titanium alloys have been used to make these conventional plate-fin heat exchangers due to the light weight and high heat capacity of the

material. These conventional heat exchangers, however, can have a problem with fin distortion during the brazing step in the manufacturing process. Titanium fins that are tall, thin and widely spaced cannot support the loads imposed on them by the fixture and heat exchanger sections on top of them.

5 This often leads to crushing of the fins and unbrazed areas within the heat exchanger. Furthermore, tall fins are difficult to form out of titanium due to cracking and the presence of burrs on offset fins.

[005] Titanium alloys also have a relatively low thermal conductivity and that is especially true of the high strength alloys. Commercially pure (CP)  
10 titanium has the highest conductivity but it also has the lowest strength which may not be suitable for a heat exchanger component. Higher conductivity fin materials of a different base metal can increase the performance of a heat exchanger.

[006] U.S. Patent Number 4,725,509 describes a braze filler and method  
15 of brazing where the filler is a titanium-copper-nickel alloy and the parent metal is titanium, nickel, cobalt or an iron-based alloy. The braze filler used in the brazing method of the patent requires a temperature of at least 1700°F (column 3, lines 1-5). Brazing at this temperature, however, may cause the filler to erode some titanium base metals, and thus, may not prove useful as a brazing  
20 method for dissimilar metals when one of the metals is a titanium alloy.

[007] U.S. Patent Number 6,168,069 describes a method of joining  
cylindrical shapes of titanium to stainless steel using a silver-copper-palladium  
braze. Silver, however, is not desirable in contact with titanium due to a  
potential for embrittlement of the titanium when in contact with liquid or solid  
25 silver. Moreover, the brazing method of this patent requires the joint be configured so that it is in compression after brazing. Finally, the brazing method of this patent requires that the joint be fitted together and the filler metal be placed outside the joint prior to brazing. Placing brazing filler outside of the

joint may not be practical when creating the thousands of fin-to-tube sheet joints as is present inside a plate-fin type heat exchanger.

[008] As can be seen, there is a need for an improved plate-fin titanium based heat exchanger that uses materials resistant to crushing at the brazing  
5 temperature while being simple to design and manufacture.

### SUMMARY OF THE INVENTION

[009] In one aspect of the present invention, a heat exchanger comprises  
10 a plurality of plate members; a first set of fins brazed between two of the plurality of plate members, with a braze filler, to form a first fluid passageway therein, wherein the first set of fins is made of a base metal different from the plurality of plate members; and a second set of fins brazed between one of the plate members, brazed to the first set of fins and another plate member, with  
15 the braze filler, to form a second fluid passageway therein, wherein the second set of fins is made of a base metal similar to or different from the plurality of plate members.

[010] In another aspect of the present invention, a heat exchanger comprises a plurality of plate members made of titanium or a titanium-based  
20 alloy; a first set of fins brazed between two of the plurality of plate members, with a braze filler, to form a first fluid passageway therein; the first set of fins being made of a base metal different from the plurality of plate members; a second set of fins brazed between one of the plate members brazed to the first set of fins and another plate member, with the braze filler, to form a second fluid  
25 passageway therein; the second set of fins made of a base metal similar to or different from the plurality of plate members; and the braze filler is able to braze materials at a temperature of less than 1700°F.

[011] In yet another aspect of the present invention, a plate-fin type heat exchanger comprises a plurality of plate members made of titanium or a

titanium-based alloy; a first set of fins brazed between two of the plurality of plate members, with a braze filler, to form a first fluid passageway therein; the first set of fins being made of a base metal different from the plurality of plate members; a second set of fins brazed between one of the plate members  
5 brazed to the first set of fins and another plate member, with the braze filler, to form a second fluid passageway therein; the second set of fins made of a base metal similar to or different from the plurality of plate members; the braze filler is composed of about 40%Ti, 20%Zr, 20%Cu and 20%Ni; and the first set of fins are made of a metal selected from the group consisting of Type 444 stainless  
10 steel, Nickel 201, Nickel Alloy 625, Type 347 stainless steel, or other stainless steel or nickel based alloys and the second set of fins are made of a titanium base alloy or from the group of alloys the first fin is selected from.

**[012]** In a further aspect of the present invention, a plate-fin type heat exchanger comprises a plurality of plate members made of a titanium or a  
15 titanium-based alloy; a first set of fins brazed between two of the plurality of plate members, with a braze filler, to form a first fluid passageway therein; the first set of fins being made of a base metal different from the plurality of plate members; a second set of fins brazed between one of the plate members brazed to the first set of fins and another plate member, with the braze filler, to  
20 form a second fluid passageway therein; the second set of fins made of a base metal similar to or different from the plurality of plate members; a third set of fins brazed between one of the plate members brazed to the second set of fins and another plate member, with the braze filler, to form a third fluid passageway therein; the third set of fins made of a base metal different from the plurality of  
25 plate members; a fourth set of fins brazed between one of the plate members brazed to the third set of fins and another plate member, with the braze filler, to form a fourth fluid passageway therein; the fourth set of fins made of a base metal similar to or different from the plurality of plate members; the braze filler is composed of about 40%Ti, 20%Zr, 20%Cu and 20%Ni; and the first set of

5 fins and the third set of fins are made of a metal selected from the group consisting of Type 444 stainless steel, Nickel 201, Nickel Alloy 625, Type 347 stainless steel, or other stainless steel or nickel based alloys and the second set of fins and the fourth set of fins are made of a titanium base alloy or from the group of alloys the first fin is selected from.

10 [013] In still a further aspect of the present invention, a method for making a plate-fin type heat exchanger comprises brazing, with a braze filler, a first set of fins between a first and second plate member to form a first fluid passageway therein, wherein the first set of fins are made of a metal different from that of the first and second plate members; and brazing, with the braze filler, a second set of fins between one of the first and second plate members and a third plate member to form a second fluid passageway therein, wherein the second set of fins are made of a metal different from that of the first, second and third plate members.

15 [014] These and other features, aspects and advantages of the present invention will become better understood with reference to the following drawings, description and claims.

#### BRIEF DESCRIPTION OF THE DRAWINGS

20

[015] Figure 1 is a perspective view of a conventional heat exchanger;

[016] Figure 2 is a side view of a brazed sample, according to the present invention, epoxy bonded to grips; and

25 [017] Figure 3 is a side view of another brazed sample, according to the present invention, epoxy bonded to grips.

#### DETAILED DESCRIPTION OF THE INVENTION

[018] The following detailed description is of the best currently contemplated modes of carrying out the invention. The description is not to be taken in a limiting sense, but is made merely for the purpose of illustrating the general principles of the invention, since the scope of the invention is best  
5 defined by the appended claims.

[019] The present invention provides a heat exchanger of the plate-fin type having fins of one base metal brazed to a plate made of a different base metal for use in oil coolers, condensers, evaporators, and the like. A base metal is the major metallic element in a metal alloy. More specifically, the  
10 distortion-prone titanium fins described in the background section may be replaced with another metal, such as a stainless steel or nickel based alloy to provide a structure that is resistant to crushing at the brazing temperature. Fluid or air flow resistance (pressure drop) through the heat exchanger may also be improved if the selected fin metal forms better fin shapes and has less  
15 burrs than titanium fins. The replacement material may also improve the heat transfer performance of the heat exchanger if the selected fin metal has higher thermal conductivity than titanium.

[020] Conventional heat exchangers often use titanium plates and fins due to the light weight and high heat capacity of the material. These  
20 conventional heat exchangers, however, have a problem with fin distortion during the brazing step in the manufacturing process. Titanium fins that are tall, thin and widely spaced have even greater difficulty in supporting the loads imposed on them by the fixture and heat exchanger sections on top of them. This often leads to crushing of the fins as well as unbrazed areas within the  
25 heat exchanger. Furthermore, tall fins are difficult to form out of titanium due to cracking and the presence of burrs on offset fins.

[021] The heat exchanger of the present invention attempts to solve these problems faced in conventional heat exchangers by replacing the distortion-prone titanium fins with another metal to provide a structure that is resistant to

crushing, that may form better fin shapes with less burrs, and that may have a higher thermal conductivity than titanium.

**[022]** The present invention is implemented by making a plate-fin type heat exchanger by using conventional titanium or titanium alloys for the material of the plates, and a different metal for the material of the fins. The fin material may be selected from any metal suitable for shaping and forming into a fin that has strength sufficient to resist crushing of the heat exchanger at operating conditions. Such a metal includes, but is not limited to, type 444 (18 Cr-2 Mo, or simply Type 444) stainless steel, nickel 201, nickel alloy 625 (Ni-21Cr-9Mo-2.5Fe) and type 347 stainless steel (18 Cr-10 Ni-Cb).

**[023]** The joining of the non-titanium-based alloy fins with the remainder of the titanium heat exchanger is of particular concern when designing such a multiple metal based heat exchanger. The present inventors have found that by using a titanium based filler material, a clean, smooth and strong bond can be made between the titanium based plates and the non-titanium based fins. A suitable titanium based filler material may have a composition of about 30 to about 50 wt% titanium, about 15 to about 25 wt% zirconium, about 15 to about 25 wt% copper, and about 15 to about 25 wt% nickel. A preferred filler material may have a composition of about 35 to about 45 wt% titanium, about 17 to about 23 wt% zirconium, about 17 to about 23 wt% copper, and about 17 to about 23 wt% nickel. A titanium based filler material that was successfully used was composed of 40%Ti, 20%Zr, 20%Cu and 20%Ni (Ti20ZR20CU20NI).

**[024]** Plate-fin type heat exchangers of the present invention may be made of any suitable size and shape, including those having cross and counter-current flows. The Examples below use a 1" X 1" square block to make the heat exchanger sample for the purposes of testing the brazing properties of the bi-metallic plate-fin heat exchanger design of the present invention. The present invention, however, is not meant to be so limited. Heat exchanger

sizes and shapes may be adjusted accordingly for use in a particular environment.

### Examples

5

[025] Referring to Figures 2 and 3, there are shown side views of a closely-spaced heat exchanger 10 and a widely-spaced heat exchanger 20, respectively, both being bonded with an epoxy 30 to grips 40. The term "top" and "bottom" as used in the description of these examples refers to the top and  
10 bottom of the page as depicted in Figures 2 and 3. All brazing in the examples was done in a vacuum at approximately 1600°F.

### Example 1

15 [026] Referring now to Figure 2, closely-spaced heat exchanger 10 was made as a 1" X 1" square with four passes arranged in a counter-current flow configuration. More specifically, a top plate 12, made from 0.005" Ti-21S, was bonded with epoxy 30 to top grip plate 42. A first set of fins 14 was made from Type 444 stainless steel and brazed to one side of top plate 12 with 0.18 g/in<sup>2</sup>  
20 Ti20ZR20CU20NI braze filler. First set of fins 14 was arranged to provide a flow in a first direction. A middle plate 16, made the same as top plate 12, was brazed to the other side of first set of fins 14 with the same Ti20ZR20CU20NI braze filler. A second set of fins 18 was made from Type 444 stainless steel and brazed to one side of middle plate 16. Second set of fins 18 was arranged  
25 to provide a flow in a direction perpendicular to the first direction. A second middle plate 16' was brazed with the same Ti20ZR20CU20NI braze filler to the other side of second set of fins 18. The same procedure was followed for a third set of fins 14' and a fourth set of fins 18'. Finally, a bottom plate 12',



brazed on one side to fourth set of fins 18', was bonded with epoxy 30 to bottom grip 44.

Example 2

5

[027] Referring now to Figure 3, widely-spaced heat exchanger 20 was made as a 1" X 1" square with four passes arranged in a counter-current flow configuration. More specifically, a top plate 22, made from 0.005" Ti-21S, was bonded with epoxy 30 to top grip plate 42. A first set of fins 24 was made from  
10 Type 444 stainless steel and brazed to one side of top plate 22 with 0.18 g/in<sup>2</sup> Ti20ZR20CU20NI braze filler. First set of fins 24 was arranged to provide a flow in a first direction. A middle plate 26, made the same as top plate 22, was brazed to the other side of first set of fins 24 with the same Ti20ZR20CU20NI braze filler. A second set of fins 28 was made from Type 444 stainless steel  
15 and brazed to one side of middle plate 26. Second set of fins 28 was arranged to provide a flow in a direction perpendicular to the first direction. A second middle plate 26' was brazed with the same Ti20ZR20CU20NI braze filler to the other side of second set of fins 28. The same procedure was followed for a third set of fins 24' and a fourth set of fins 28'. Finally, a bottom place 22',  
20 brazed on one side to fourth set of fins 28', was bonded with epoxy 30 to bottom grip 44.

Example 3

25 [028] A second closely-spaced heat exchanger was prepared in a manner and of materials the same as those used for Example 1.

Example 4

[029] A widely-spaced heat exchanger was prepared in a manner similar to that used for Example 1, however, the Type 444 stainless steel fins used in  
5 Example 1 were replaced with Ni-201 fins.

Results

[030] Table 1 shows the results of a tensile test for the four above  
10 described examples. Grips 42 and 44 were pulled apart with the test subject epoxy bonded thereto. The breaking load and failure locations were noted.

**Table 1. Plate-Fin Heat Exchanger Tensile Results**

Example	Breaking load (pounds)	Failure Location
1	2270	Brazed joint
2	330	Brazed joint
3	1810	Brazed joint
4	476	Epoxy

15 [031] The above results show excellent bonding between the Ti-21S plate material with the non-titanium based fin material. The table shows excellent brazing between the closely-spaced Type 444 stainless steel fins with the Ti-21S plate material (Examples 1 and 3). Adequate brazing was also demonstrated with the widely-spaced Type 444 stainless steel fin material  
20 (Example 2). The exact fin/plate tensile strength could not be determined specifically for the example using the Ni-201 fin material (Example 4). This sample detached at the epoxy bond before the brazed fin broke. Therefore, the brazed joint breaking load was >476 pounds.

**[032]** When the heat exchanger of Example 1, having Type 444 stainless steel fins, was brazed to the Ti-21S sheet, the fin-to-sheet joints had large smooth fillets with good wetting, as evidenced by small contact angles at the toe of the fillets. No erosion of the Type 444 stainless steel fins was noted.

5 **[033]** When the heat exchanger of Example 2, having Type 444 stainless steel fins, was brazed to the Ti-21S sheet, the fin-to-sheet joints had large smooth fillets with good wetting, as evidenced by small contact angles at the toe of the fillets. Again, no erosion of the Type 444 stainless steel fins was noted.

10 **[034]** Furthermore, when the heat exchanger of Example 4, having Nickel-201 fins, was brazed to the Ti-21S sheet, the fin-to-sheet joint had large smooth fillets with good wetting. No erosion of the Nickel-201 fins was noted.

**[035]** It should be understood, of course, that the foregoing relates to preferred embodiments of the invention and that modifications may be made without departing from the spirit and scope of the invention as set forth in the following claims. Such modifications could be heat exchangers with more or less numbers of passages, fin materials that alternate in passage-pairs or that have variations in base metal throughout the heat exchanger stack, metal plates and closure bars that are made from non-titanium base metal, fins that are all titanium base with plates or closure bars that are non-titanium base metal, or plates, fins and bars made from other titanium alloys such as Ti-15-3-3-3, Ti-21S, Ti-3.2.5, Commercially Pure Titanium, Ti-6-2-4-2, Ti-6-4 as examples.

15  
20